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(57) Abstract

A method and apparatus for predicting the likelihood of an avatar under the control of a user in a virtual environment moving with a predetermined range of a boundary as disclosed in which the movement of the avatar in the virtual environment is monitored for a period of time, a model of avatar movement is determined using the monitor movement, and the likelihood of the avatar movement within the predetermined of a boundary is predicted using the model.

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PREDICTING AVATAR MOVEMENT IN A DISTRIBUTED VIRTUAL ENVIRONMENT

The present invention generally relates to a distributed virtual environment in which the movement of an avatar controlled by a user is predicted. In particular, the present invention relates to a distributed virtual environment which is divided into zones wherein the likelihood of an avatar moving within a predetermined range of a zone boundary is predicted.

A virtual environment is a computer model of a three-dimensional space. At their most basic virtual environment applications allow a user to specify a "camera" location from which they wish to view the space. The application then renders the appropriate view of the environment from this location and presents it to the user on a monitor of the computer running the application. With this degree of functionality virtual environments can be used in a wide variety of visualisation applications e.g. taking a walk around a building not yet constructed.

Most virtual environment applications are however considerably more sophisticated than this and offer both an environment populated with objects (termed entities) which possess both a state and behaviour, and a means for the user to interact with these entities.

Virtual environments have many applications. One which has become particularly popular is in the field of

computer games. Games such as Doom and Quake allow a user to control an entity to interact with the virtual environment modifying the state of entities within the virtual environment.

A further development of the virtual environment concept is the shared virtual environment. This involves a number of users, each with their own copy of the relevant virtual environment application (termed a client) experiencing a three dimensional space which is common to them all. Each user not only perceives the results of their interactions with the entities but also the results of other users interactions. To represent the location of a user in a shared virtual environment a special case of entity, known as an avatar is employed. This provides a visual representation on all of the clients as to where a particular user is viewing the scene from.

A shared virtual environment is usually implemented using a computer network wherein remote users operate clients in the network which incorporates servers for the virtual environment.

For simple virtual environments, where the number of entities is limited, implementing a shared version is comparatively straightforward. As each user joins the virtual environment a client is provided with the current state of all entities within it. As the environment state changes, due to either user invoked behaviour or

autonomous behaviour, the newly generated state information is distributed to all clients, allowing a common view between different clients to be maintained.

However, for larger virtual environments, where both the number of simultaneous users and entities is large, this approach breaks down. This is because the amount of information required to supply and support a total description of state at each client overwhelms either the network connection of the client or the processing power available to the client.

One common solution to this problem is to utilise the fact that a client does not need to maintain a valid state description of any entities its user is unaware of. For example, if two avatars are playing tennis, it is important that both their clients are kept fully informed of the position of the ball. However, for the users who can't see or hear the tennis court it is not necessary to inform them of either the ball state or the state of the avatars playing tennis. Only when they move into a position where the court can be observed is this information required.

A common implementation of this solution sub-divides the environment into a number of regions, termed zones and then groups the entities on the basis of the zone they occupy. Each users avatar location is then used to assess what zones the user is aware of, and the client is informed of the state of all entities within these

zones. As entities update their state they broadcast the change only to the clients aware of their current zone. In this way the network and processing load on each client is proportional to the state changes in their avatars surrounding location, rather than the total environment.

An example of an implementation of this type of this approach is NPSNET (Macedonia *et al* "NPSNET: A Network Software Architecture for Large Scale Virtual Environments", Presence, Volume 3, No. 4, Fall 1994) the content of which is hereby incorporated by reference. In this implementation the virtual environment is divided into a number of hexagonal zones and a multicast address is associated with each zone. Each client maintains a network connection to the multicast address of the zone its avatar is in. This address is used by the client to broadcast any avatar state change e.g. movement. Additionally the client also maintains network connections to the multicast address of any zones the user is aware of i.e. within visual or aural range. Hence two clients with neighbouring avatars will share avatar state updates by virtue of using common multicast addresses. However, two users widely separated within the virtual environment will not share awareness of any zones and hence will not load each others network connection with shared state information.

Figure 1 is an illustration of this zonal distributed virtual environment. As can be seen in Figure 1 an avatar has a range of awareness which comprises a volume which is often spherical and is centred on an avatar. This range of awareness encloses all the entities that a client needs to possess the state of in order to accurately display the world to the user. The volume is often defined with respect to the visual range of any rendering performed at the client although it may be derived from the range of any of the relevant senses e.g. hearing.

In Figure 1 the illustrated area of the virtual environment is divided into nine geographic areas or zones each of which has a multicast address associated with it. Client A has an avatar A in zone 3 and has a range of awareness which spans into zones 2 and 6. Thus, client A monitors zones 2, 3 and 6. Since the avatar A can modify the state of entities in zone 3, and since the avatar state changes, updates are made using the multicast address for zone 3. Avatar B has a visual range which encompasses zone 3 and client B therefore listens to zone 3's multicast address as well as zone 2's multicast address in which the avatar B is present. Therefore, any changes to avatar A will be detected by client B and similarly any changes to avatar B will be detected by client A. In contrast, avatar C has no visual awareness of zones 2 or 3 and therefore client C

does not listen to their multicast addresses. This reduces the network load.

Figure 2 is a schematic diagram of a network hosting the virtual environment schematically illustrated in Figure 1. Nine servers (1-9) are illustrated interconnected by a communications network 10 such as a local area network (LAN) or a wide area network (WAN). Each server is responsible for a respective geographical zone in the virtual environment and receives and transmits the status of the zone using a unique multicast address assigned for the zone. Also connected to the communications network 10 are three clients, client A (11), client B (12) and client C (13). Each client hosts an avatar and thus maintains the virtual environment experienced by the avatar. As described above each client will connect to a multicast address i.e. to a server dependent upon the zones of which an avatar is aware. A client can either comprise a workstation or an application i.e. a computer program running on a computer. Thus a single computer may host more than one client. Similarly a server can either comprise a dedicated computer or an application i.e. a computer program running on a computer. Thus a single computer may host more than one server.

In an alternative arrangement disclosed in our copending Application No. GB 9722343.2 filed on 22 October 1997, the content of which is hereby

incorporated by reference, zone managers are responsible for managing each zone within the virtual environment and thus the location of the avatar within the virtual environment and the awareness range of the avatar will determine the communications required between the client and the zone managers.

In this arrangement objects in the virtual environment have a conceptual model, a dynamics model and a visual model. A rule manager is associated with the conceptual model. The visual model is provided at each client and the dynamic model is associated with the zone managers. Thus only dynamics information needs to be passed between the zone managers and the clients.

A problem identified by the inventors in a zoned distributed environment is how to link avatar movement to zone awareness. Figure 3 illustrates this problem. Avatar A is in zone 1 and moving towards the boundary between zone 1 and zone 2. Client A is therefore aware of the state of the entities within zone 1 (entities 1 and 2) but is unaware of the state of any of the entities within zone 2 (entities 3 and 4). In some point in the future, avatars A awareness will overlap into zone 2 and client A must become fully informed of the state of all entities in zone 2 (entities 3 and 4).

If client A only starts to fetch the initial state of the entities in zone 2 at the point avatar A becomes initially aware of zone 2 i.e. the awareness region

touches the boundary between zones 1 and 2, a number of problems can arise:

1. Graphical inconsistency. While the initial state of the zone is being fetched the avatar may continue moving towards it. Hence the avatar may be in the visual range of entities which have not yet been supplied. When the initial state download is complete these entities will suddenly appear, giving a visual glitch.

2. User control problems. If the avatar is prevented from moving whilst fetching the state of a zone (in an effort to prevent the graphical inconsistency described above), it will reduce the interactive nature of the client user interface.

3. State Inconsistency. If the avatar is moving fast enough it may even cross into the next zone before its client has a full description of all the relevant entities. This could lead to the client trying to make invalid state settings. For example, placing the avatar in the middle of a wall because at the time the avatar moved the client was unaware of the wall entity.

In order to overcome this problem, one aspect of the present invention provides a method and apparatus for predicting the likelihood of an avatar under the control of a user in a virtual environment moving within a predetermined range of a boundary, wherein the movement of the avatar in the virtual environment is monitored for

a period of time, the model of the avatar movement is determined using the monitored movement, and the likelihood of the avatar moving within the predetermined range of a boundary is predicted using the model.

Thus, by monitoring movement of the avatar in the virtual environment for a period of time the pattern of movement can be determined which enables a model to be built. This can then be used to predict avatar movement. The accuracy of the model is important in order to avoid unnecessary downloading of state information. If the current velocity in a direction is simply extrapolated from the current position for a time, a simple prediction can be made. However, such a simple prediction fails to take into account a number of factors that directly affect the probability of an avatar coming within the range of a boundary. A highly experienced user, who knows the environment well, will be able to plan paths in advance and move quickly between known land marks. This will result in long, predictable avatar trajectories. By contrast an inexperienced user will need to stop frequently to reaffirm their position, and will not be able to use known land marks to plan an avatar path. This will reduce the predictability of their avatar. Also, environments such as games and military stimulations where avatar paths are a key part of the user interaction, will result in more predictable avatar trajectories than those where navigation does not play

a key role. For example, a large open room used as a chat space will result in fairly static avatars (whilst chatting in groups), with occasional short paths to random parts of the room (when a user spots somebody they want to talk to). By contrast, a game (e.g. Doom or Quake) where the typical goals are "travel to this door", "traverse this door", "find this key", etc will have far more mobile avatars, moving to specific points, and hence producing more predictable paths. Further, the mechanism for controlling an avatar normally has to map the output of the numerous different devices (keyboard, mouse, joystick, tracker ball, etc) into the six degrees of freedom available to an avatar (rotation and translation in three dimensional space). The device and map being used will impact on the trajectory taken by the avatar. For example, using a mouse output mapped directly to an avatar's horizontal motion will result in bursts of short jerky motions. By contrast a keyboard input by its digital nature will tend to produce paths of more consistent motion.

By utilizing a model of avatar movement, these factors can be taken into account to provide a more accurate prediction of the likely behaviour of an avatar based on its past behaviour.

In a virtual environment in accordance with one aspect of the present invention each client utilises an avatar motion predictor which monitors avatar motion in

a recent period of time to establish a pattern of avatar behaviour in order to predict the likelihood of an avatar becoming aware of a neighbouring zone.

In order to determine the model of avatar behaviour, movement samples e.g. position, orientation, or velocity can be obtained for a set number of previous avatar movement samples. As new avatar movement information is supplied the model is continuously updated discarding the effect of older movement samples, thus ensuring that the model is of the avatar's current style of movement.

The prediction technique can take into consideration features within the virtual environment which restrict movement of the avatar e.g. a window through which the avatar cannot move but through which the avatar can see into a neighbouring zone. In such a case although the avatar can see into the neighbouring zone, it cannot move into the zone in that direction and must instead take a different path. Thus environmental features will effect the predicted likelihood for example by reducing the predicted likelihood when a wall lies between the avatar and the boundary.

Prediction can also be performed taking into consideration features within the virtual environment which restrict the ability of the avatar to experience the virtual environment e.g. fog or a darkened room. Thus although the avatars awareness zone extends over a boundary into a neighbouring zone, because of the

conditions, the awareness range of the avatar is reduced and thus there is no need to fetch the information on the neighbouring zone since it cannot be experienced by the avatar.

The model can be determined as values for run lengths indicating the likelihood of an avatar moving in a direction for a particular length. Alternatively, the model can be determined as run lengths within a corridor indicating the likelihood of the avatar moving within a corridor in a direction for a particular corridor length. A corridor comprises a region in the virtual space coaxial with an initial direction of movement in a new direction outside a previous corridor. The width of the corridor defining the deviation allowed from the initial direction of movement before the movement is used to start a new run length.

In another embodiment the model comprises values for areas around the avatar indicating the likelihood of the avatar moving into the areas. In a further embodiment the model comprises values for directions and distances of movement of the avatar for periods of time.

Using the probability of an avatar moving within an awareness range of a neighbouring zone, together with known network and processing penalties of establishing zone awareness, the client can determine the time at which awareness of the zone should be attained i.e. when information on the state of entities within the zone

should be retrieved over the network. If the penalty for fetching the state of the entities in a particular zone is very high on the client network link, the client may decide to wait until the avatar prediction model forecasts a 90% chance of awareness of that zone in the next second, alternatively, if the penalty is low it might decide to play safe and fetch the state of the zone when the model only predicts a 20% chance in the next two seconds.

Thus in accordance with one embodiment of the present invention a more efficient distributed virtual environment is provided by using the prediction together with a cost function related to the client network connection and/or client processing capability or load in order to determine when to establish awareness of a neighbouring zone.

Since the present invention can be implemented in software running on a computer or over a network, the present invention can be embodied as a storage medium storing instructions for controlling a computer to carry out the method and a signal carrying computer code for controlling a computer to carry out the method.

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of the NPSNET multicast arrangement;

Figure 2 is a schematic diagram of a network hosting the virtual environment schematically illustrated in Figure 1;

Figure 3 is a schematic diagram of an avatar approaching a zone boundary;

Figure 4 is a schematic illustration of a network hosting the virtual environment incorporating the prediction technique of an embodiment of the present invention;

Figure 5 is a schematic diagram of an embodiment of the present invention;

Figure 6 is a diagram illustrating the termination of the intersection boundary from the zone boundary;

Figure 7 is a schematic diagram of point to point avatar motion;

Figure 8 is a flow diagram illustrating the determination of the model using run lengths;

Figure 9 is a flow diagram illustrating the method of using the model in order to determine when a client should become aware of the neighbouring zone;

Figure 10 is a diagram of avatar movement within corridors;

Figure 11 is a flow diagram of the determination of the model from the motion of Figure 10;

Figures 12a to 12d illustrate a method of forming the model of avatar movement over an area;

Figure 13a is a flow diagram of a first method of determining a model using the technique of Figure 12;

Figure 13b is a flow diagram of a second method of determining a model using the technique of Figure 12;

Figure 14 is a method of using the model to determine avatar awareness of a neighbouring zone using the method of Figure 12;

Figures 15a and 15b illustrate the model using angle and distance;

Figures 16a to 16e illustrate a method of determining the model of Figures 15a and 15b;

Figure 17 is a flow diagram of the method of Figures 14a to 14e; and

Figure 18 is a flow diagram illustrating the method of using the model in order to determine avatar awareness of a neighbouring zone.

Figure 4 is a schematic illustration of a network in accordance with an embodiment of the present invention. The network comprises servers 21 and 22 interconnected over a communications network 25 to clients 23 and 24. The network is thus similar to Figure 2 except a motion predictor 26 or 27 can be provided in the client 23 or the server 21 respectively (although the figure illustrates both only one will be provided in

practice). The clients 23 and 24 and the servers 21 and 22 can be implemented as a computer program running on a host computer thus allowing multiple clients and servers on a single computer. The motion predictor 26 or 27 can be implemented as a computer program on a computer hosting a client or a server. The location is not important so long as access to information on avatar movement and the virtual environment is available. The communications network 25 can be any form of network such as a LAN or a WAN.

Figure 5 illustrates one embodiment of the present invention schematically wherein a virtual environment application 30 is hosted on a virtual environment client 31 controlling avatar movement from which is available the current avatar movement and environment information. Avatar movements for previous time periods are also output and a sliding window of samples (termed the model time frame hereinafter) is used by the motion predictor 32 to build a model of avatar motion. The environment information is used to determine the proximity of the zone boundary to the avatar. Within the virtual environment application 30 the motion predictor 32 predicts the likelihood of an avatar coming within a predetermined range of the boundary of the zone. This prediction is used by a virtual environment client 31 in order to determine when to fetch the state information for a neighbouring zone.

As mentioned above, the motion predictor 31 need not necessarily be placed on the same computer as the virtual environment client 31. If the responsibility for establishing client awareness of a zone is moved to a server e.g. the same server that delivers the zone state information, the motion predictor 31 can be placed on the server.

Since the motion predictor continually builds its model of avatar motion using new avatar movement samples as they are supplied by the client, it will dynamically adapt to new types of motion. For example, if the user redefines the application interface in a way that gives less predictable avatar motion, as new avatar movements samples are fed into the prediction model this new uncertainty will be reflected in the output of the motion predictor. This will again enable the client to modify its policy for establishing its awareness of new zones.

In normal operation the client will want an assessment of the avatars awareness crossing into a zone. This is equivalent to detecting whether an avatar is within an awareness range of the zone boundary. It is thus possible to determine an intersection boundary which is provided at the avatars awareness ranged from the zone boundary as illustrated in Figure 6. Thus instead of predicting whether the awareness zone will cross the zone boundary, it can equivalently be predicted whether the avatar will cross the intersection boundary. This

technique of predicting the coincidence of the avatar position with the intersection boundary rather than predicting coincidence of the avatars awareness range d with the zone boundary simplifies the computation.

In Figure 6 at an area marked "e" a small error occurs where the intersection boundary should in fact be rounded to ensure that it always lies at a distance d from the zone boundary. This error can however, be assumed to be negligible.

In the embodiments described hereinafter the prediction is thus a prediction of whether the avatar will cross the intersection boundary as illustrated in Figure 6. In all of the following embodiments the position of the avatar is monitored at movement sample periods and the samples are used to populate each model. A window of samples, termed a model time frame, are used to form each model and the size of the set of samples and the frequency of its update is implementation dependent. When selecting the size of the set the implementation should ensure:

1. The set is large enough to reflect the general style of avatar motion, and not temporary types of motion caused by the local environment. For example, an avatar walking down a spiral staircase will be forced to adopt a curved path. A very small sample set in this scenario would cause the prediction model to reflect avatar motion

as regularly changing direction, when this may not be indicative of the more unconstrained motion.

2. The set is small enough to allow the prediction model to adapt to new types of motion within a reasonable time frame. If the set is too large it may reflect multiple styles of avatar motion simultaneously which will seriously impair the accuracy of the predictions.

A first embodiment of the present invention will now be described with reference to Figures 7 to 9.

Figure 7 illustrates avatar movement from sample point to sample point and treats the avatar movement as a series of straight runs each run comprising two or more sample points. In this embodiment the prediction model consists of a table of run lengths against a probability of occurrence. Such a table is illustrated below:

Run length (m)	Number of occurrences	Likelihood
0.0 - 1.0	1000	1.0
1.0 - 2.0	870	0.87
2.0 - 3.0	700	0.7
3.0 - 4.0	500	0.5
4.0 - 5.0	300	0.3
5.0 - 6.0	100	0.1
6.0 - 7.0	10	0.01
>7.0	0	0

Figure 7 illustrates five runs in a model time frame of 30 samples. Each run length from sample 1 to 7, 7 to

11, 11 to 19, 19 to 21 and 21 to 30 is termed a prediction time frame and thus each model time frame consists of a variable number of variable length prediction time frames. When the direction of movement is detected as changing, a new prediction time frame (run length) is started.

In the table above the model time frame comprises 1001 samples (the first sample acting as a reference point). Occurrences are incremented not for a final run length but for each run length up to the final run length e.g. a total run length of 2.3 metres will result in an occurrence in each of the first three rows i.e. 0.0-1.0, 1.0-2.0 and 2.0-3.0. All run lengths have a length of at least between 0 and 1 metres. The number of run lengths having progressively longer run lengths decreases and no run lengths are longer than 7 metres. The table also includes a likelihood value which is calculated from the number of occurrences for a run length divided by the total number of occurrences i.e. the model time frame length minus 1. This is calculated each time the table entries are changed to keep the table up-to-date. The table is used by using the distance the avatar is away from the intersection boundary as an input to match to a run length to output the likelihood e.g. if the distance is 1.8 metres there is an 87% chance that the avatar will cross the boundary in this run, but if the

distance is 8 metres there is no chance that the avatar will cross the boundary in this run.

Figure 8 is a flow diagram illustrating how the table of run lengths and likelihoods comprising the model is formed.

In step S1 initially the first two samples are entered and a sample counter n is set to equal 2. In step S2 the current run length is determined and in step S3 the entry in the table for the current run length is incremented. The likelihood values in the table are then updated in step S4 and the next sample point is awaited in step S5. When the next sample point is received, in step S6 the length of the current sample in the model time frame is incremented i.e. n is set equal to n + 1 and in step S7 it is determined whether the number of current sample points in the model time frame is equal to the maximum number of sample points N. If not, in step S8 it is determined whether there has been a change in direction and if not the process returns to step S2 wherein the current run length is determined. If a change in direction has been determined in step S8, in step S9 the run length is restarted from the previous sample point and the process returns to step S2.

If in step S7 it is determined that the model time frame is full, in step S10 the first sample point in the model time frame is incremented to the first sample point in the second prediction time frame in the model time

frame i.e. to the second run length in the prediction time frame. The table entries corresponding to the first prediction time frame in the model time frame are then removed in step S11 so that the effect of the first time frame is removed from the model. In this way the model is kept up-to-date only taking into consideration the most recent run lengths.

Having deleted the oldest prediction time frame (run length) in step S11 the process then proceeds to step S8 to determine whether there has been a change in direction brought about by the new sample point. If there has been no change in direction the run length is determined in step S2 but if there has been a change in direction in step S9 the run length is restarted from the previous sample point and then the run length is determined in step S2.

Figure 9 is a flow diagram illustrating how the model is used. In step S12 the distance to the zone boundary is input and in step S13 this is used to look-up the likelihood for a corresponding run length. Thus a likelihood of the avatar moving within a predetermined range of the boundary is determined. In step S14 this can be compared with a threshold to determine whether or not to request information on the status of the zone beyond the boundary in step S15. The threshold percentage used in step S14 can be predetermined independently to the implementation environment or it can

be set in dependence upon the operating conditions e.g. the current network loading, the network loading required to obtain the status information, the current processing load, and the expected processing load for downloading the status information.

A second embodiment of the present invention will now be described with reference to Figures 10 and 11.

This embodiment of the present invention is similar to the first embodiment except that instead of measuring a run length as being from "point to point", a run length is calculated along a corridor. This allows for some deviation in the path before it is considered that the avatar has changed direction. Figure 10 illustrates the use of corridors to define run lengths.

Figure 11 is a flow diagram illustrating the operation of this embodiment. In step S16 the first two samples are input in the model time frame and the sample counter is set to equal 2. In step S17 the current run length within a corridor is determined and in step S18 the entry in the table for the current run length is incremented. In step S19 the likelihood values in the table are updated and in step S20 the next sample point is awaited. When the next sample point is received in step S21 the length of the current samples in the model time frame are incremented such that n is set equal to n + 1. In step S22 it is then determined whether the number of current sample points in the model time frame

equals N i.e. is the model time frame full, and if not the process proceeds to step S23 wherein it is determined whether there is a change in direction. If not, the process returns to step S17 whereupon the current run length within a corridor is determined. If a change of direction is determined in step S23, in step S24 the run length is restarted from the previous sample and the process returns to step S17.

If in step S22 it is determined that the model time frame is full, the first sample point in the model time frame is incremented to the first sample point in the second prediction time frame in the model time frame and in step S26 corresponding table entries for the first prediction time frame (the first run length) are removed. The process then proceeds to step S23.

This embodiment can be considered to be a more relaxed version of the embodiment illustrated with reference to Figures 7 and 8 since the run length embodiment illustrated in Figures 7 and 8 can be considered to have a corridor of 0 width.

A third embodiment of the present invention will now be described with reference to Figures 12 to 14.

This approach attempts to map avatar motion into a probability area of occupation. As can be seen in Figure 12a the avatar motion can be seen as a number of paths between points and this is broken up in the method to a series of segments 1 to 7.

Each of the segments comprises a prediction time frame. As illustrated in Figure 10a the model time frame thus comprises seven prediction time frames in this embodiment.

Referring to the flow diagram of Figure 13a which illustrates a first method, in step S30 the first sample point of a prediction time frame is used as the origin of the model and thus the prediction time frame is relatively aligned with the origin of the model. In step S31 the prediction time frame is relatively aligned with the model using the path to the reference sample point as illustrated in Figure 10b. The reference sample point comprises a first sample point in a segment and thus a first sample point in the prediction time frame. The path to the reference sample point is illustrated as "u" in Figure 10b. In step S32 the next sample point is then received and the sample point counter n is incremented. In step S33 it is then determined whether the number of sample points n is equal to N i.e. the model prediction time frame is full. If not in step S34 the avatar path to the next sample point is defined and in step S35 for areas through which the avatar path passes within a predetermined area i.e. within the circle of Figures 10b, 10c and 10d, table entries are incremented. In step S36 it is then determined whether the next sample point is outside the predetermined area i.e. whether it is the first point in a next prediction time frame. If not the

process returns to step S32 to receive the next sample point. If the next sample point is outside the area in step S37 the sample point is made the reference sample point and the process returns to step S30 whereupon the reference sample point is aligned with the origin of the model.

If in step S33 it is determined that the model time frame is full and another sample point has been received, in step S38 the first sample point in the model time frame is incremented to the first sample point in the second prediction time frame i.e. to a first sample point of the second segment. Then in step S39 the table entries for the first prediction time frame in the model are removed and the process proceeds to step S36. In this way the model time frame becomes a sliding time frame so that the model only takes into account recent behaviour of the avatar.

In the flow diagram of Figure 13a the model time frame is moved along one prediction time frame at a time. Thus, the model time frame moves coarsely in jumps. In an alternative embodiment the model time frame is moved along point by point wherein the last prediction time frame of samples in a model is used each time to increment table entries.

This method is illustrated in Figure 13b. In step S300 the last prediction frame of samples in a model time frame of samples is selected and in step S310 the origin

of the model is relatively aligned with a reference sample point as can be seen in Figure 12b. The reference sample point comprises a first sample point in a segment. In step S320 the prediction time frame is relatively aligned with the model using the path to the first reference sample point. This is illustrated as "u" in Figure 12b. The avatar path to the next sample point is then defined in step S330 and in step S340 for areas through which the avatar path passes within a predetermined area (i.e. within the circle of Figures 12b, 12c, and 12d) table entries are incremented.

In step S350 it is determined whether the end of the prediction frame has been reached and if not in step S360 it is determined whether the sample point lies outside the predetermined area i.e. the circle in Figures 12b to 12d. If not, the process returns to step S330 to find the next avatar path in the segment. If the sample point is outside the circle in step S350 the sample point is redefined as the reference sample point in step S370 and the process then returns to step S32 wherein the next segment is time aligned with the model.

It can thus be seen that steps S320 to S370 are repeated until all of the paths of the segments 1 to 7 have been mapped into the model to accumulate counts for the areas shown as squares Figure 12c through which the paths pass. The counts accumulated in the table for each of the areas are indicated in Figures 12c and 12d by

shading where the darker shading illustrates a higher count.

If in step S350 the end of the prediction time frame has been reached, the first sample point in the model time frame is incremented in step S380 and the table entries for the oldest sample in the model time frame are removed in step S390. The process then returns to step S300 to repeat for the next prediction frame.

In order to utilise the model to predict the likelihood of an avatar crossing the intersection boundary, as illustrated in Figure 14 in step S40 the boundary position and angle is input and in step S41 the boundary is overlaid on the model as illustrated in Figure 12d. The counts for the zones crossed by the boundary are then added up in step S42 and in step S43 the counts are calculated as a percentage of the total number of counts in the model. The likelihood generated in step S43 is then compared with a threshold in step S44 and if the threshold is exceeded in step S45 the client will request information on the status of the zone beyond the boundary.

A fourth embodiment of the present invention will now be described with reference to Figures 15 to 18.

In this embodiment successive periods of avatar motion (sample sequences from the sample subset) are analysed against a series of potential zone boundaries

to build a probability of boundary crossing model. This model is expressed as a table with three dimensions:

1. Angle between avatar direction of motion and zone boundary line.

2. Distance between avatar position and zone boundary line.

3. Time.

The granularity of this table is determined by the processing power available to the predictor. For a very fine grained table, each sequence of samples in the sample subset is compared against a large number of potential boundaries, over a wide range of times, and the table populated with the results. The coarser of the table granulator the fewer the boundary comparisons and less representation is required.

For example, if the model uses a granularity of 30 degrees and forward distance steps to approximate relative zone boundaries, 48 boundary representations will be produced. This is illustrated in Figure 15a. Note that the zone boundaries are considered to extend to infinity in both directions such as shown in Figure 15b for a set of boundaries at a particular distances.

A method of this embodiment of the present invention will now be described with reference to Figures 16 and 17.

The last prediction frame of samples in the model time frame of samples is selected in step S50. This is

assuming that this has been carried out iteratively throughout the model time frame for prediction frames starting at each sample point that finishes outside the outer boundary segment of the model as for the previous embodiment. The origin of the model is relatively aligned with a reference sample point which comprises the first sample point in the prediction frame (step S51). In step S52 the prediction time frame is relatively aligned with the model using the path to the reference sample point. The results of steps S51 and S52 can be seen in Figure 16a.

In step S53 the avatar path to the next sample point is defined as shown in Figure 16b and in step S54 any table entries for boundaries across which the avatar path passes are incremented. In Figure 16b no boundaries are crossed and thus no table entries are incremented. In step S55 it is then determined whether the prediction time frame has been processed i.e. whether the last sample point is outside the outer boundary, and if not the process returns to step S53. As can be seen in Figure 16c the path to the next sample point is defined and this crosses eight of the theoretical boundaries which are incremented. Since each sample point corresponds to a time period these entries are made corresponding to that particular time period. For example, if the sample rate is 10 hertz the entries at 0.2 of a second would be incremented in the table.

Figure 16d illustrates the next loop through steps S53 to S55 wherein table entries for 0.3 of a second are implemented for the 11 boundary segments crossed.

Figure 16e illustrates the path from the fourth to fifth sample at 0.4 seconds and the 14 boundary segments crossed.

It should be noted that the determination of the boundary segments crossed is not made in dependence upon the path to each point it is made in dependence upon the path from the origin to the sample point. Hence the number of boundary segments crossed increases for each sample point in the prediction time frame.

Each boundary segment corresponds to entry of the table indexed by angle and distance and since the samples are input with respect to time, at each sample time, a different set of entries are made.

In step S56 at the end of the prediction time frame the number of counts in the prediction time frame is added to the running total for the model time frame i.e. the entries for the three dimensional table for the most recent prediction time frame is added into the three dimensional table for the previous prediction time frames of the model time frames.

The process then awaits the next sample in step S57 and when the next sample is received in step S58 the first sample point in the model time frame is incremented and in step S59 the table entries for the oldest sample

in the model time frame are removed in order to update the table. The process then returns to step S50 so that the prediction time can be moved along one sample point within the model time frame.

Figure 18 is a flow diagram illustrating how the table is used. In step S60 the distance angle and time to the zone boundary are input and used in step S61 as three coordinates to look-up the number of counts in the table. The looked-up counts are then calculated as a percentage of the total number of counts in the table in step S62 in order to return a likelihood of the avatar crossing the intersection boundary. In step S63 it is then determined whether the percentage is above the threshold and if so, in step S64 the client requests information on the status of the zone beyond the boundary.

As for the pervious embodiments, the threshold in step S63 can be predetermined and can be dependent on a cost function such as network and processing penalties of establishing zone awareness.

Although in all the above embodiments the likelihood is shown as being obtained directly from the table (model) this likelihood can be modified to take into account the virtual environment between the avatar and the boundary e.g. if a wall is between the avatar and the boundary the likelihood can be reduced accordingly. Thus

the predictor can not only take into account avatar movement but also the local environment.

By determining the likelihood of the avatar awareness region crossing into a zone it is possible to determine when and if to download the state of a zone of which the client is not currently aware. Since the downloading of the state of a zone imposed by the network and processing load of the client, the use of the model to provide an accurate prediction reduces the likelihood of unnecessarily downloading the state information. Also, once in a current state of a zone has been fetched it is necessary to track all the state changes that occur within it to ensure that the state stays current. Therefore, the accurate prediction produces the unnecessary traffic and processing load associated with an unnecessary download and updating.

In accordance with the embodiment of the present invention by taking into consideration the known network and processing penalties of establishing zone awareness, it is also possible for the client to control and tune the downloading of state information in order to suit the current state of the hardware implementing the virtual environment.

The present invention can be implemented in any type of zonal distributed virtual environment such as the NSPNET system and the system described in copending application number GB 9722343.2.

Although the present invention has been described hereinabove with reference to specific embodiments, it is apparent to a skilled person in the art that modifications are possible within the spirit and scope of the present invention.

CLAIMS:

1. Apparatus for predicting the likelihood of an avatar under the control of a user in a virtual environment moving within a predetermined range of a boundary, the apparatus comprising:

monitoring means for monitoring movement of said avatar in said virtual environment for a period of time so as to obtain movement data;

model means for determining a model of avatar movement using the movement data; and

prediction means for predicting the likelihood of said avatar moving within said predetermined range of said boundary using said model.

2. Apparatus according to claim 1 wherein said model means is adapted to determine a dynamic model using only movement monitored within a recent time period.

3. Apparatus according to claim 1 or claim 2 wherein said monitoring means is adapted to monitor the position of said avatar with time in said virtual environment.

4. Apparatus according to any preceding claim wherein said prediction means is adapted to perform said prediction taking into consideration features within said virtual environment which restrict movement of said

avatar.

5. Apparatus according to any preceding claim wherein said prediction means is adapted to perform said prediction taking into consideration features within said virtual environment which restrict the ability of said avatar to experience the virtual environment.

6. Apparatus according to any preceding claim wherein said predetermined range is dependent upon a range of awareness of said avatar within which said avatar can experience the virtual environment, and said prediction means is adapted to perform said prediction taking into consideration features within said virtual environment which restrict the range of awareness of said avatar.

7. Apparatus according to any preceding claim wherein said prediction means is adapted to predict a likelihood of said avatar moving within said predetermined range of said boundary within a predetermined period of time.

8. Apparatus according to any preceding claim wherein said monitoring means is adapted to provide time sampler of the position of said avatar, and said model means is adapted to determine a dynamic model which is updated every n^{th} sample from said monitoring means using the n most recent samples, and which is formed using a

plurality m of most recent sets of n samples from said monitoring means.

9. Apparatus according to any preceding claim wherein said model means is adapted to determine said model as set of values for directions and distances of movement of said avatar.

10. Apparatus according to any one of claims 1 to 8 wherein said model means is adapted to determine said model as values for areas around said avatar indicating the likelihood of said avatar moving into said areas.

11. Apparatus according to any one of claims 1 to 8 wherein said model means is adapted to determine said model as values for run lengths indicating the likelihood of said avatar moving in a direction for a particular length.

12. Apparatus according to any one of claims 1 to 8 wherein said model means is adapted to determine said model as values for run lengths within a corridor indicating the likelihood of said avatar moving within a corridor in a direction for a particular corridor length.

13. A system for providing a distributed virtual

environment, the apparatus comprising:

one or more servers for maintaining said virtual environment as a plurality of zones;

a client for providing a user interface to the virtual environment to allow a user to control an avatar in the virtual environment, wherein said client is adapted to communicate with one or more of the servers only with regard to one or more zones in the proximity of said avatar; and

apparatus for predicting the likelihood of said avatar moving within a predetermined range of a boundary of a zone according to any one of claims 1 to 12;

wherein said client is adapted to communicate with one or more of the or each servers to obtain information on the status of one or more further zones when the likelihood of the avatar moving within a predetermined range of the boundary of said one or more further zones is above a threshold.

14. A system according to claim 13 wherein said client is adapted to communicate with said one or more servers to obtain information on the status of one or more further zones when the likelihood of the avatar moving within a predetermine range of the boundary of said one or more further zones is above a threshold and in dependence upon at least one of the amount of communication traffic, the time taken for the

communication with the or each servers, and the processing power required as a result of the communication.

15. A client for use with a computer system for providing a distributed virtual environment which includes one or more servers for maintaining said virtual environment as a plurality of zones, the apparatus comprising:

interface means for providing a user interface to the virtual environment to allow a user to control an avatar in the virtual environment wherein the interface means is adapted to communication with one or more of the or each servers only with regard to a number of zones in the proximity of said avatar; and

apparatus for predicting the likelihood of said avatar moving within a predetermined range of a boundary of a zone according to any one of claims 1 to 12;

wherein the said interface means is adapted to communication with one or more of the or each servers to obtain information on the status of one or more further zones when the likelihood of the avatar moving within a predetermined range of the boundary of said one or more further a zones is above a threshold.

16. A client according to claim 15 wherein said interface means is adapted to communication with said one

or more servers to obtain information on the status of one or more further zones when the likelihood of the avatar moving within a predetermine range of the boundary of said one or more further zones is above a threshold and in dependence upon at least one of the amount of communication traffic, the time taken for the communication with the or each servers, and the processing power required as a result of the communication.

17. A method of predicting the likelihood of an avatar under the control of a user in a virtual environment created by a computer system moving within a predetermined range of a boundary, the method comprising the following steps performed by said computer system:

monitoring movement of said avatar in said virtual environment for a period of time;

determining a model of avatar movement using the monitored movement; and

predicting the likelihood of said avatar moving within said predetermined range of said boundary using said model.

18. A method according to claim 17 wherein said model is determined is a dynamic model using only movement monitored within a recent time period.

19. A method according to claim 17 or claim 18 wherein the movement of said avatar is monitored by monitoring the position of said avatar with time in said virtual environment.

20. A method according to any one of claims 17 to 19 wherein said prediction is preformed taking into consideration features within said virtual environment which restrict movement of said avatar.

21. A method according to any one of claims 17 to 20 wherein said prediction is performed taking into consideration features within said virtual environment which restrict the ability of said avatar to experience the virtual environment.

22. A method according to any one of claims 17 to 21 wherein said predetermined range is dependent upon a range of awareness of said avatar within which said avatar can experience the virtual environment, and said prediction is performed taking into consideration features within said virtual environment which restrict the range of awareness.

23. A method according to any one of claims 17 to 22 wherein said prediction is a prediction of a likelihood of said avatar moving within said predetermined range of

said boundary within a predetermined period of time.

24. A method according to any one of claims 17 to 23 wherein the monitoring provides time samples of the position of said avatar in said virtual environment, and said model is determined as a dynamic model which is updated every n^{th} sample using the n most recent samples, and which is formed using a plurality m of most recent sets of n samples.

25. A method according to any one of claims 17 to 24 wherein said model is determined as set of values for directions and distances of movement of said avatar.

26. A method according to any one of claims 17 to 24 wherein said model is determined as values for areas around said avatar indicating the likelihood of said avatar moving into said areas.

27. A method according to any one of claims 17 to 24 wherein said model is determined as values for run lengths indicating the likelihood of said avatar moving in a direction for a particular length.

28. A method according to any one of claims 17 to 24 wherein said model is determined as run lengths within a corridor indicating the likelihood of said avatar

moving within a corridor in a direction for a particular corridor length.

29. A method of using a computer system to provide a distributed virtual environment, the method comprising the following steps performed by the computer system:

maintaining said virtual environment as a plurality of zones using one or more servers;

controlling a client to provide a user interface to the virtual environment to allow a user to control an avatar in the virtual environment, wherein said client communicates with one or more of the servers only with regard to one or more zones in the proximity of avatar;

predicting the likelihood of said avatar moving within predetermined range of a boundary of a further zone using the method of any one of claims 17 to 28;

wherein said client communicates with said one or more servers to obtain information on the status of said further zone when the likelihood of the avatar moving within a predetermined range of the boundary of said further zone is above a threshold.

30. A method according to claim 29 wherein the communication with said one or more servers is further dependent upon a cost function associated with the potential degradation in performance experienced by a user.

31. A method according to claim 30 wherein the communication is further dependent upon at least one of the amount of communication traffic, the time taken for the communication with said servers, and the processing power required as a result of the communication.

32. A method of providing a client in the method of claim 29, the method comprising:

providing a user interface to the virtual environment to allow a user to control an avatar in the virtual environment, wherein the user interface only communications with one or more of the servers with regard to a number of zones in the proximity of said avatar;

predicting the likelihood of said avatar moving within a predetermined range of a boundary of a further zone using the method of any one of claims 17 to 28,

wherein the user interface communicates with said one or more servers to obtain information on the status of said further zone when the likelihood of the avatar moving within a predetermined range of the boundary of said further zone is above a threshold.

33. A method according to claim 32 wherein the communication with said one or more servers is further dependent upon a cost function associated with the potential degradation in performance experienced by a

user.

34. A method according to claim 33 wherein the communication is further dependent upon at least one of the amount of communication traffic, the time taken for the communication with said servers, and the processing power required as a result of the communication.

35. A storage medium storing instructions for controlling a computer to carry out the method of any one of claims 17 to 34.

36. A signal carrying computer implementable instructions for controlling a computer to carry out the method of any one of claims 17 to 34.

Fig.1.

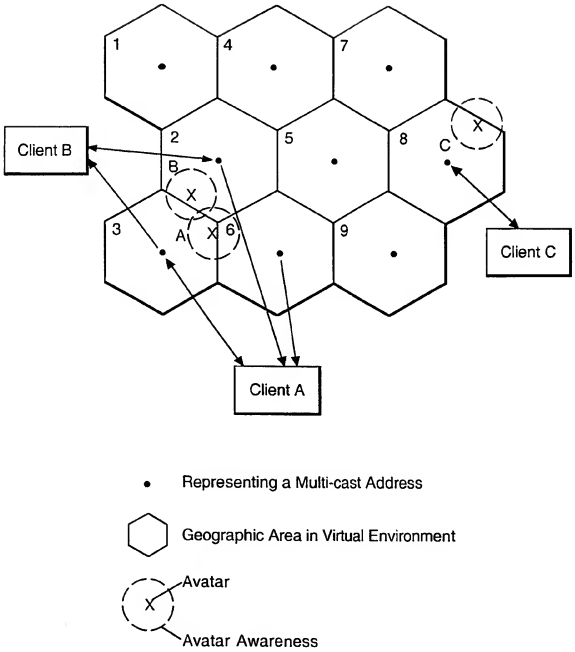

1
4
7
2
5
8
3
6
9
X
C
B
X
A
X
X
Client B
Client C
Client A
Representing a Multi-cast Address
Geographic Area in Virtual Environment
Avatar
Avatar Awareness

Fig.2.

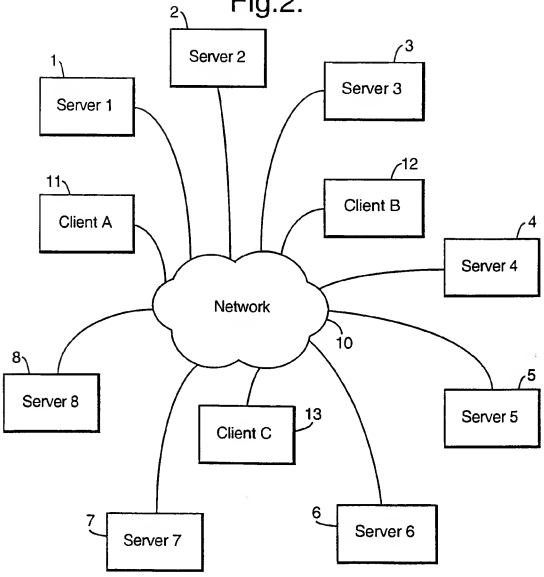

1
Server 1
2
Server 2
3
Server 3
4
Server 4
5
Server 5
6
Server 6
7
Server 7
8
Server 8
10
Network
11
Client A
12
Client B
13
Client C

Fig.3.

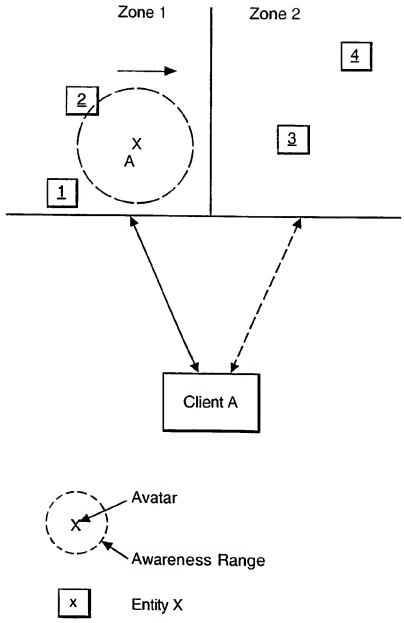

Zone 1
Zone 2
4
2
X
A
3
1
Client A
Avatar
X
Awareness Range
x
Entity X

Fig.4.

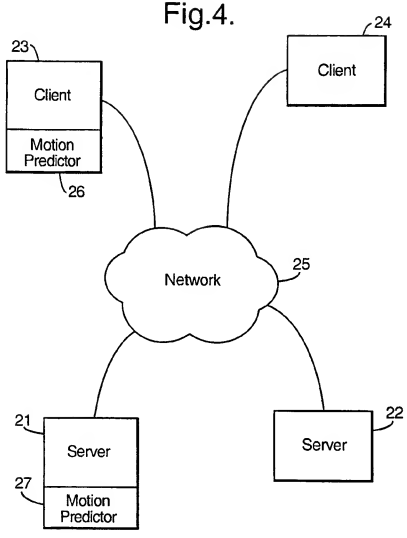
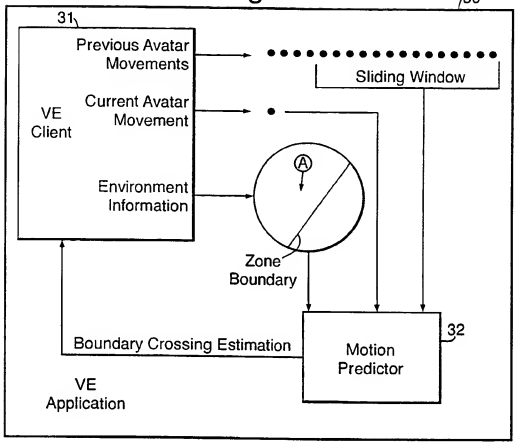

23
Client
Motion Predictor
26
24
Client
Network
25
21
Server
27
Motion Predictor
22
Server

Fig.5.



• Avatar Movement Sample e.g. Position, Velocity, etc

Fig.6.

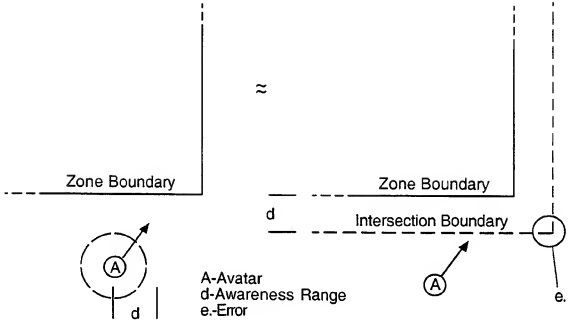

≈
Zone Boundary
Zone Boundary
d
Intersection Boundary
A
A
d
A-Avatar
d-Awareness Range
e.-Error
e.

Fig.7.

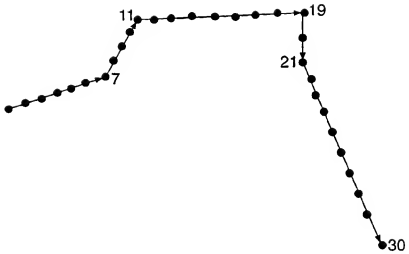


Fig.8.

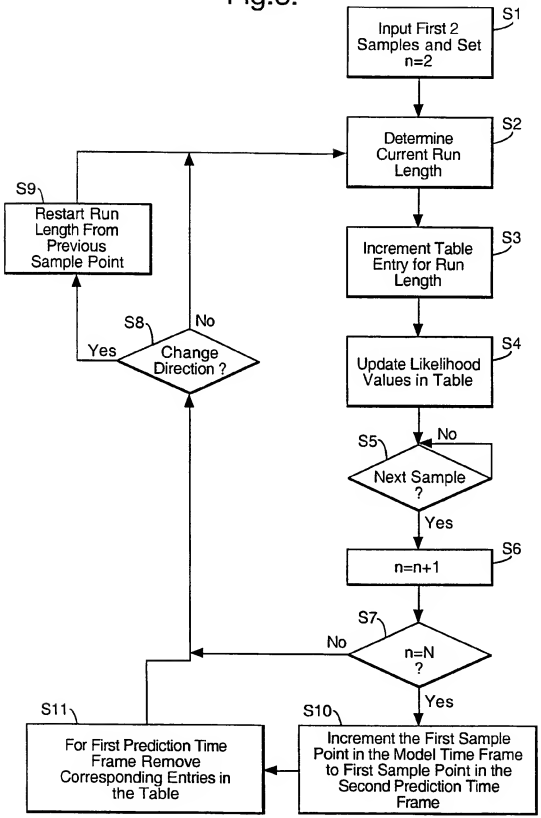

Input First 2 Samples and Set n=2
S1
Determine Current Run Length
S2
Increment Table Entry for Run Length
S3
Update Likelihood Values in Table
S4
Next Sample ?
S5
No
Yes
n=n+1
S6
n=N ?
S7
No
Yes
Change Direction ?
S8
No
Yes
Restart Run Length From Previous Sample Point
S9
Increment the First Sample Point in the Model Time Frame to First Sample Point in the Second Prediction Time Frame
S10
For First Prediction Time Frame Remove Corresponding Entries in the Table
S11

Fig.9.

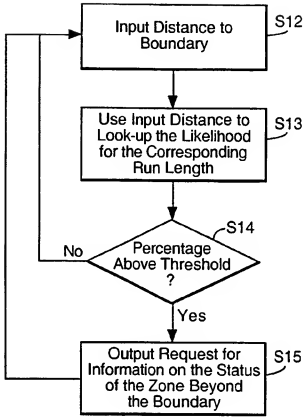

Input Distance to Boundary
S12
Use Input Distance to Look-up the Likelihood for the Corresponding Run Length
S13
S14
Percentage Above Threshold ?
No
Yes
Output Request for Information on the Status of the Zone Beyond the Boundary
S15

Fig.10.

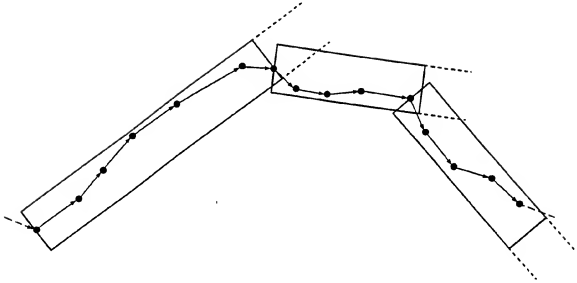
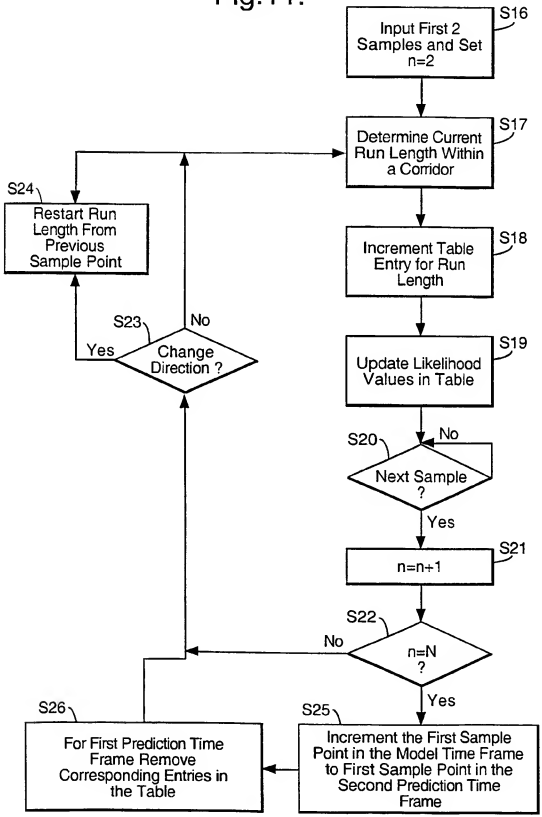


Fig.11.


Input First 2 Samples and Set n=2
S16
Determine Current Run Length Within a Corridor
S17
Increment Table Entry for Run Length
S18
Update Likelihood Values in Table
S19
Next Sample ?
S20
No
Yes
n=n+1
S21
n=N ?
S22
No
Yes
Increment the First Sample Point in the Model Time Frame to First Sample Point in the Second Prediction Time Frame
S25
For First Prediction Time Frame Remove Corresponding Entries in the Table
S26
Change Direction ?
S23
No
Yes
Restart Run Length From Previous Sample Point
S24

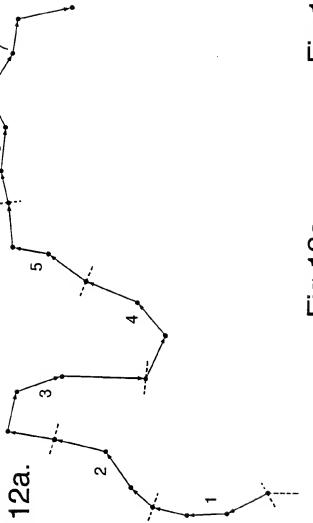


Fig.12a.

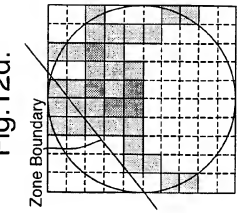


Fig.12d.

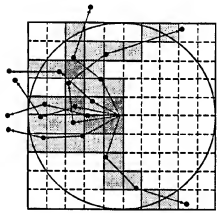


Fig.12c.

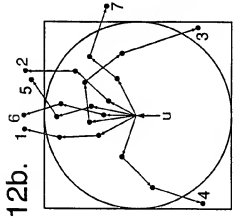


Fig.12b.

Fig.13a.

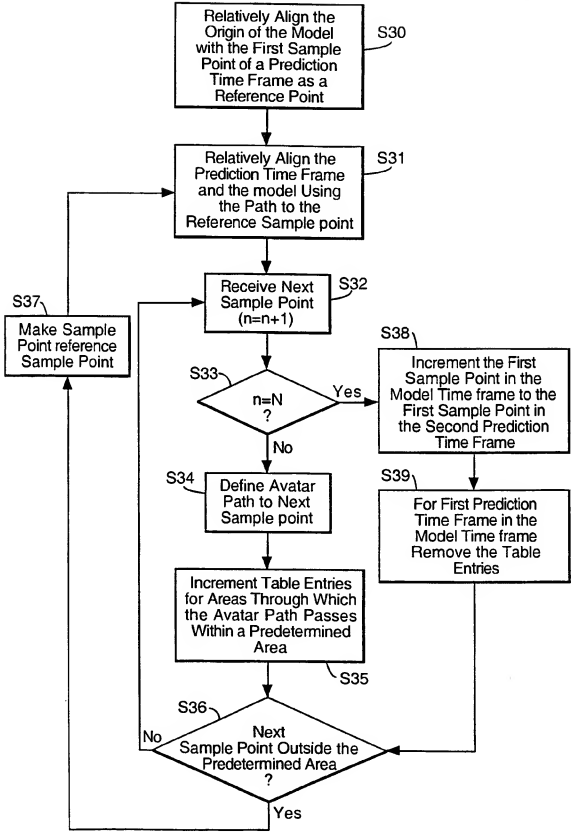

Relatively Align the Origin of the Model with the First Sample Point of a Prediction Time Frame as a Reference Point
S30
Relatively Align the Prediction Time Frame and the model Using the Path to the Reference Sample point
S31
Receive Next Sample Point (n=n+1)
S32
S37
Make Sample Point reference Sample Point
S33
n=N ?
Yes
No
S38
Increment the First Sample Point in the Model Time frame to the First Sample Point in the Second Prediction Time Frame
S34
Define Avatar Path to Next Sample point
S39
For First Prediction Time Frame in the Model Time frame Remove the Table Entries
Increment Table Entries for Areas Through Which the Avatar Path Passes Within a Predetermined Area
S35
S36
Next Sample Point Outside the Predetermined Area ?
No
Yes

Fig.13b.

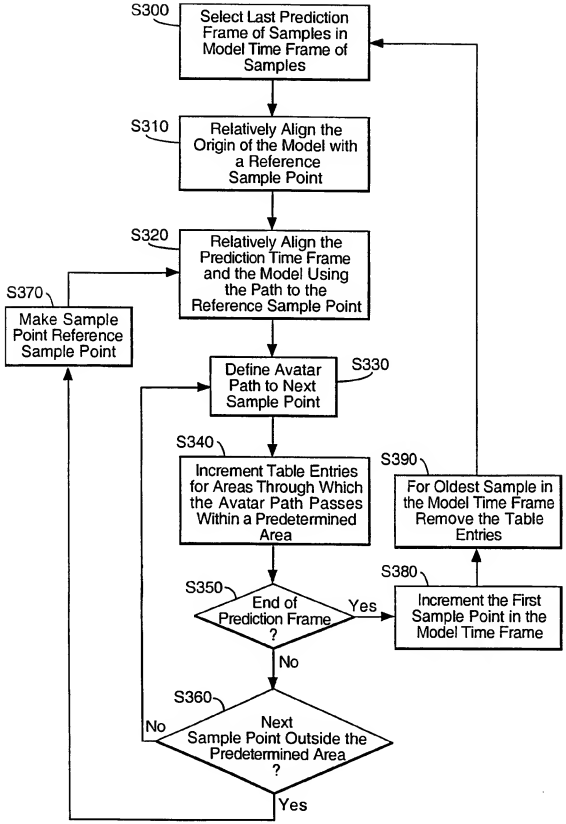

S300
Select Last Prediction Frame of Samples in Model Time Frame of Samples
S310
Relatively Align the Origin of the Model with a Reference Sample Point
S320
Relatively Align the Prediction Time Frame and the Model Using the Path to the Reference Sample Point
S370
Make Sample Point Reference Sample Point
Define Avatar Path to Next Sample Point
S330
S340
Increment Table Entries for Areas Through Which the Avatar Path Passes Within a Predetermined Area
S390
For Oldest Sample in the Model Time Frame Remove the Table Entries
S380
Increment the First Sample Point in the Model Time Frame
S350
End of Prediction Frame ?
Yes
No
S360
No
Next Sample Point Outside the Predetermined Area ?
Yes

Fig.14.

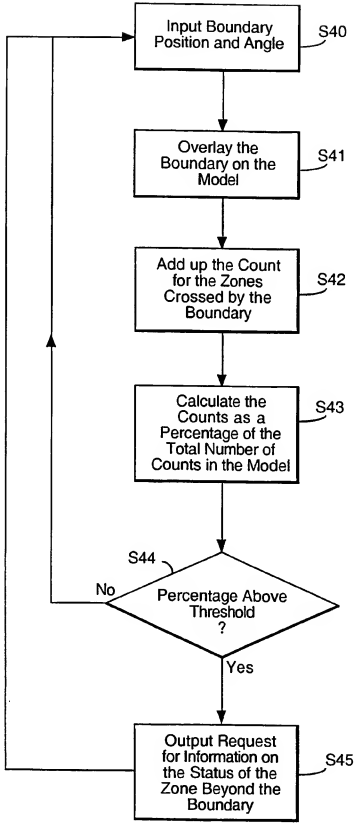

Input Boundary Position and Angle
S40
Overlay the Boundary on the Model
S41
Add up the Count for the Zones Crossed by the Boundary
S42
Calculate the Counts as a Percentage of the Total Number of Counts in the Model
S43
S44
No
Percentage Above Threshold ?
Yes
Output Request for Information on the Status of the Zone Beyond the Boundary
S45

Fig.15a.

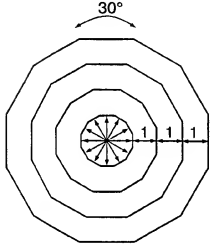


Fig.15b.

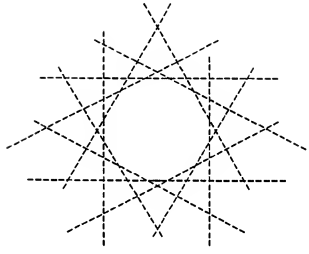


Fig.16a.

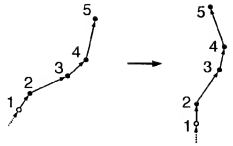
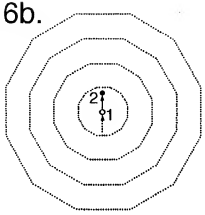
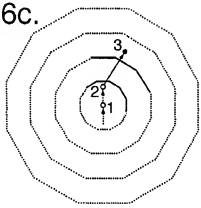


Fig.16b.



Boundary Segment not crossed

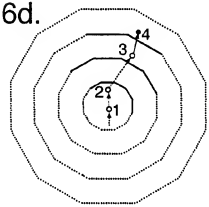
Fig.16c.



Boundary Segment not crossed

Boundary Segment crossed

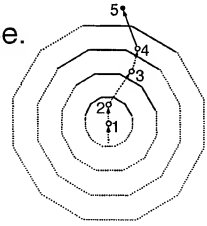
Fig.16d.



Boundary Segment not crossed

Boundary Segment crossed

Fig.16e.



Boundary Segment not crossed

Boundary Segment crossed

Fig.17.

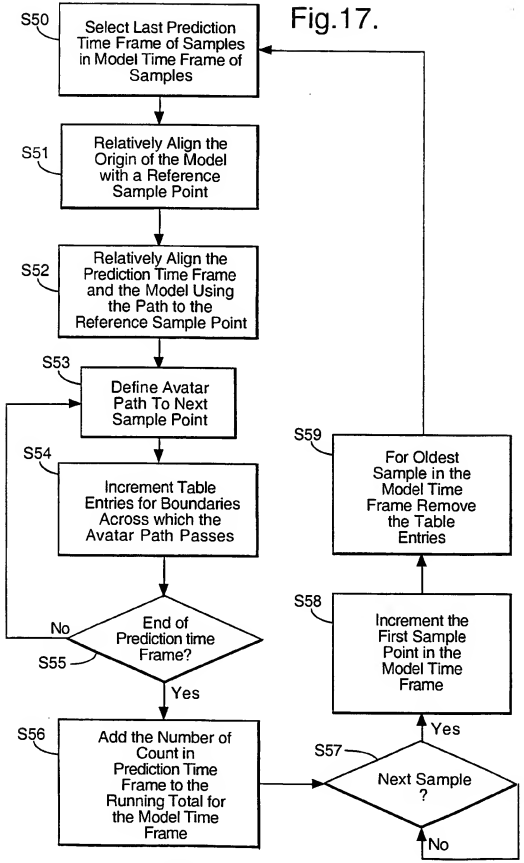
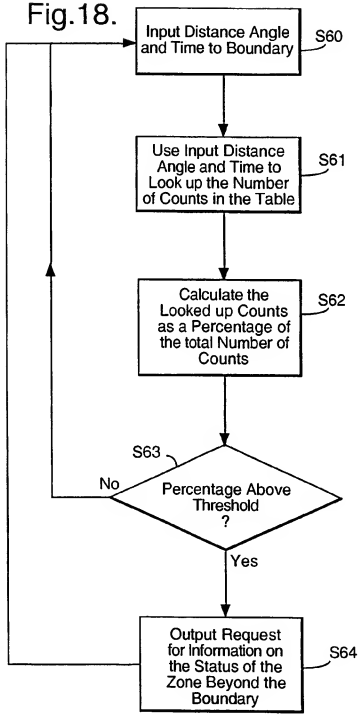

S50
Select Last Prediction Time Frame of Samples in Model Time Frame of Samples
S51
Relatively Align the Origin of the Model with a Reference Sample Point
S52
Relatively Align the Prediction Time Frame and the Model Using the Path to the Reference Sample Point
S53
Define Avatar Path To Next Sample Point
S54
Increment Table Entries for Boundaries Across which the Avatar Path Passes
End of Prediction time Frame?
No
S55
Yes
S56
Add the Number of Count in Prediction Time Frame to the Running Total for the Model Time Frame
S57
Next Sample ?
Yes
No
S58
Increment the First Sample Point in the Model Time Frame
S59
For Oldest Sample in the Model Time Frame Remove the Table Entries

Fig.18.


Input Distance Angle and Time to Boundary
S60
Use Input Distance Angle and Time to Look up the Number of Counts in the Table
S61
Calculate the Looked up Counts as a Percentage of the total Number of Counts
S62
S63
No
Percentage Above Threshold ?
Yes
Output Request for Information on the Status of the Zone Beyond the Boundary
S64